TACOM

Lethality, Survivability, Mobility and Sustainment for America's Army

USE OF DESIGNED EXPERIMENTS IN THE "GREEN AMMUNITION" PROGRAM

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Report Documentation Page

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Abstract

Subject Terms

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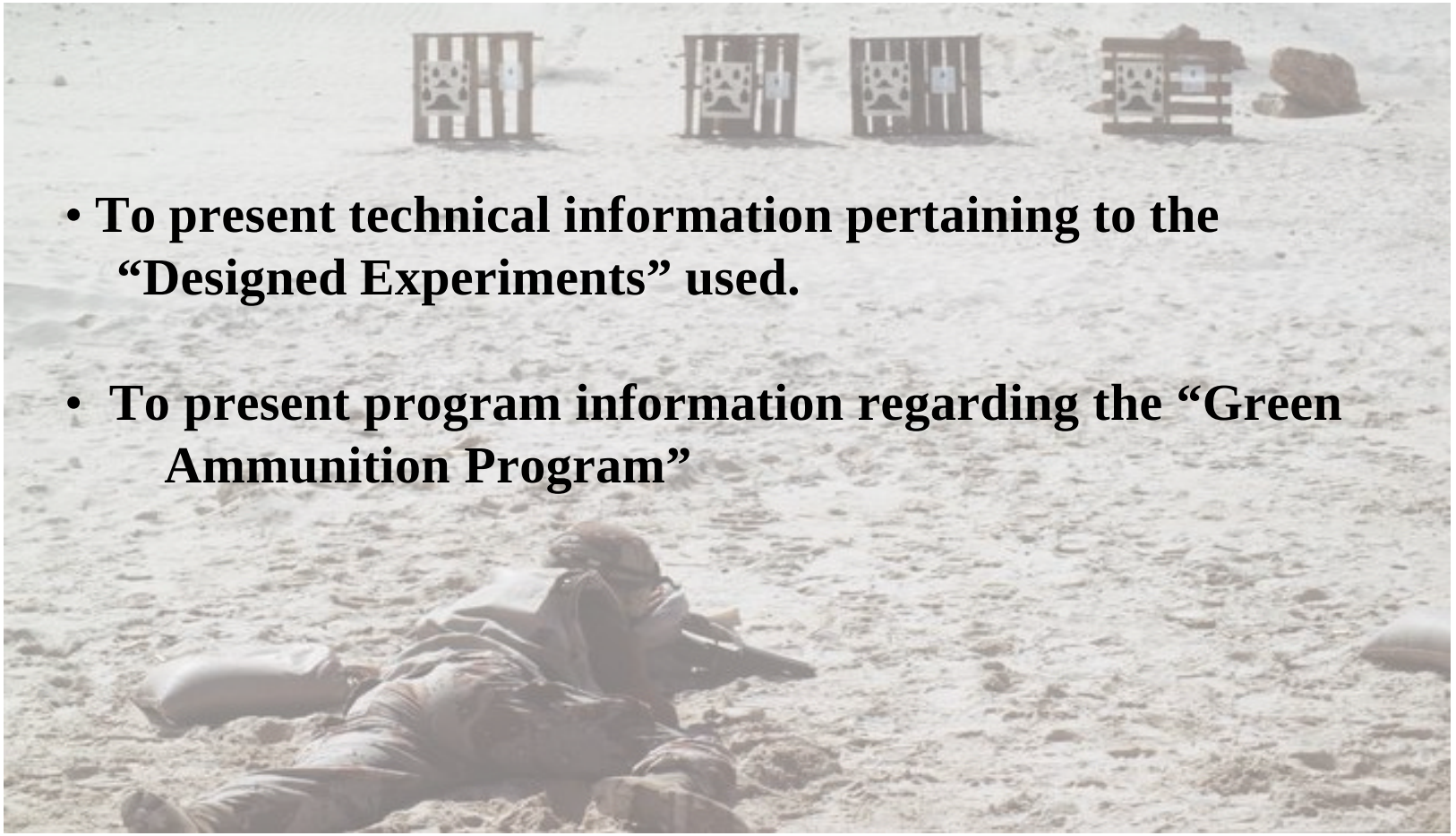
31

Objective



- **To present technical information pertaining to the "Designed Experiments" used.**
- **To present program information regarding the "Green Ammunition Program"**

Green Ammunition

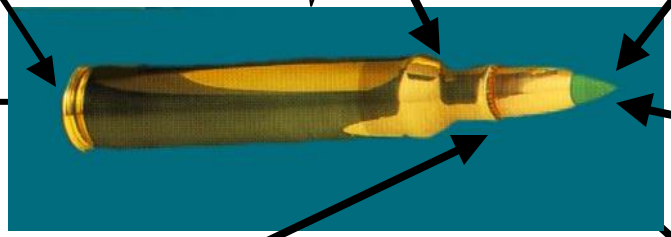
Target Materials

VOCs
Primer Pocket Sealant
Lacquer Thinner MEK
Xylene MIK
Toluene

ODCs
Casemouth Sealant
Methyl Chloroform

VOCs
Blank Ctg Tip Sealant
Ethyl Acetate Toluene
MEK Xylene
MIK

HEAVY METALS
Primer Compositions
Lead Styphnate
Barium Nitrate
Antimony Sulfide



VOCs
Combat Ctg Tip ID
Glycol

Tracer & Ignitor Compositions

VOCs
Ethyl Alcohol

HEAVY METALS
Barium Peroxide
Lead Dioxide
Barium Nitrate

ODCs
Methyl Chloroform

HEAVY METALS
Projectile Slug
Lead\Antimony

Non-Toxic Ammunition History

- FY91-93 - Services Initiate Independent In-House Efforts Based on Tightening Environmental Regulations
- Services Duplicating Efforts
- August 4, 1993 President Clinton Signs Executive Order 12856
- Sept 94: Initial Formation Tri-Service Working Group (ARDEC, NAVY, AF) to Identify Needs and Goals for Each Service
- Early 95: Continued On-Going Discussions Led to the Development of Specific Needs, Goals, and Initial Thrust Areas
- Oct 95: JWG Formed to Pursue Elimination of Toxic Materials from Ammunition

Joint Working Group for Non-Toxic Ammunition

CHAIR - ARDEC

Naval Surface Warfare Center - Crane
Naval Surface Warfare Center - Indian Head
Naval Air Warfare Center- China Lake
Air Force- AFCEE -
Air Force - Randolph AFB
Marine Corps System Command- Arlington
Coast Guard HQ-Washington
National Guard HQ- Arlington
USAIC- Ft. Benning
US Army Reserve Command
Army Center for Health Promotion & Prevention Medicine
Naval Special Warfare - Coronado
Ft Dix Force Projection

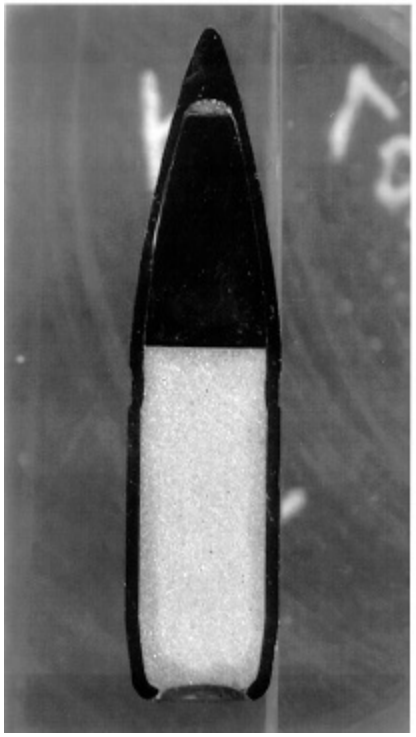
Formed by ARDEC in October 1995

Army Environmental Center- Edgewood
Army Training & Support Center- Ft. Eustis
Industrial Operations Command
Lake City Army Ammunition Plant

DOE- Oak Ridge National Lab
DOE- Los Alamos National Lab
DOE- Kansas City Plant
Federal Bureau of Investigation
Federal Law Enforcement Training Center

Projectile Core Replacement Efforts

- 5.56mm M855 Ball cartridge completed
  - ✓ Effort initiated ’96 with SERDP Funding
  - ✓ Intended to be invisible to the Users.
    - ➢ Use existing Specification Requirements
  - ✓ Two candidates qualified
  - ✓ Field Tested
    - ➢ Stewart River, Alaska
    - ➢ MMR, Camp Edwards
  - ✓ 1M+ cartridges available to field in Dec 99
  - ✓ Currently procuring 50M cores for FY00
  - ✓ Plans to procure 50M cores for FY01
  - ✓ Optimization efforts on-going for both cores



Caliber .50 lead replacement completed

- Underway: 5.56mm M856 Tracer, 7.62mm & 9mm,
- Seeking funding to investigate .22 cal. Match

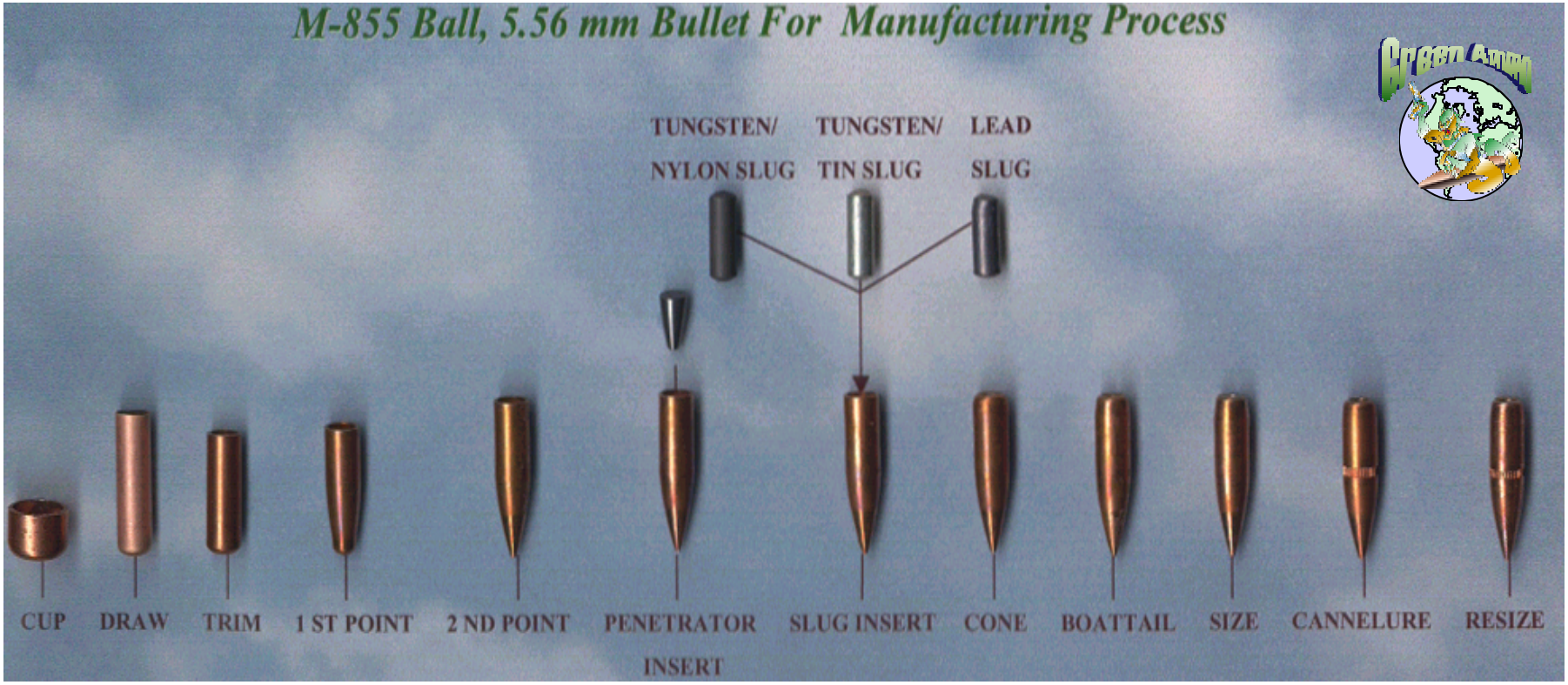
HOW DID WE GET THERE?

1997
Fact Finding

- Industry Responses Solicited – Search for Drop-In Replacement
- 7 Samples Obtained
- Samples Manufactured on Existing Equipment
- Test Firings Against Existing Specifications
  - •Accuracy
  - •Velocity
  - •Chamber Pressure
- 2 Samples Accepted for Further Exploration
  - ✓ Tungsten/Tin
  - ✓ Tungsten/Nylon

Bullet Assembly Process

- **Lake City Army Ammunition Plant manufactures 5.56mm - Cal..50 ammunition for the Army.**
- **Operated by Alliant Techsystems (ATK)**



1998-1999
Development and Initial Fielding

- Production Runs Range in Size Up to 100,000 Pieces
- All Production To Existing Procedures
  - ✓ No Dimensional Changes
  - ✓ Olin Corporation: CP2 and ISO 9000 Certified
  - ✓ No Deviation from In-Process Control Testing
- Full Acceptance Testing to All Specification Requirements
- Additional Testing Included:
  - ✓ Target Penetration
  - ✓ Barrel Erosion to 15,000 Rounds per Weapon (SAW)

Projectile Core Replacement Efforts

Stewart River, Alaska

- Field Test at Stewart River, Alaska - Aug ‘98

- Conducted by the 1st Battalion, 297 Infantry
- New Range Facility in Pristine area.
- Riflemen were shooting for qualification
- 5,200 rds fired by 72 riflemen for Qualification

“Green Ammunition had no adverse impact on qualifying soldiers”

MAJ Garry W. Curtiss

Projectile Core Replacement Efforts

Massachusetts Military Reservation

- First Firing of Production Green Bullet M855, October ‘99

- Massachusetts Military Reservation (Camp Edwards)
- Training had been suspended for 2 years.
- 211th Military Police Battalion
- Riflemen were shooting for qualification
- 58 Riflemen Qualified (one perfect score)

1998-1999
Development and Initial Fielding

How Do We Know the New Materials Are Environmentally Friendly?

- Toxicological and Bio-Uptake Studies Performed by Oak Ridge National Laboratory.

- Testing Included:
  - Leaching / Mobility
  - Plant Growth (Rye Grass)
  - Earthworms

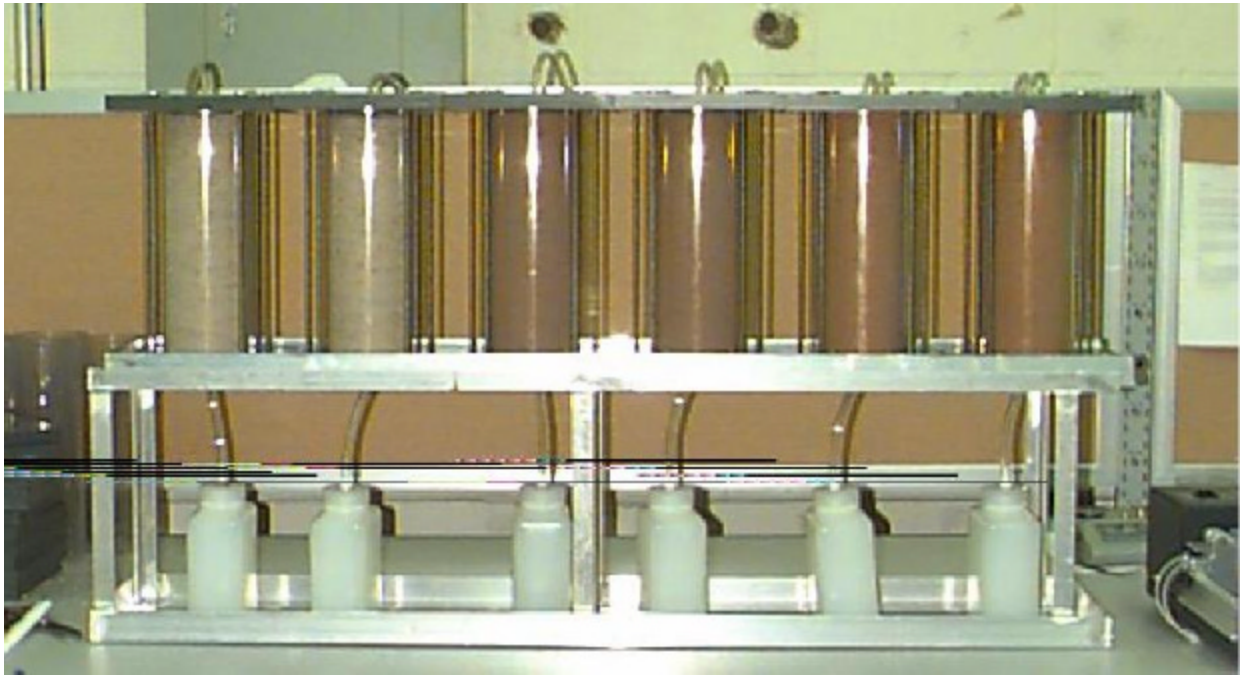
- These Tests Performed to Existing Standards.

Bullet Fragments

Bullets Recovered from Sand and Other Media Were Used to Guide the Development of Simulants for the Leaching Studies

Leaching Columns

Leaching Columns as Specified in ASTM and EPA Standards were Modified for this Activity



Leaching Experiments Have Been Conducted to Simulate Conditions Expected at Ranges

Standard Runs	Solvent	Media	Technique	Status
1	**Deionized Water**	**Sand**	**Up-flow**	**Complete**
2	**Deionized Water**	**Sand**	**Hold**	**Complete**
3	**Deionized Water**	**Soil**	**Up-flow**	**Complete**
4	**Deionized Water**	**Soil**	**Hold**	**Complete**
5	**Ocean Water**	**Sand**	**Up-flow**	**Complete**
6	**Ocean Water**	**Sand**	**Hold**	**Complete**
7	**Rain Water**	**Sand**	**Up-flow**	**Complete**
8	**Rain Water**	**Sand**	**Hold**	**Complete**
9	**Rain Water**	**Soil**	**Up-flow**	**Complete**
10	**Rain Water**	**Soil**	**Hold**	**Complete**

Specialty Runs	Solvent	Media	Technique	Status
1	Rain Water	Chipped Tires	Up-flow	Planned
2	Rain Water	Soil + Limestone	Up-flow	Planned
3	Rain Water	Soil + LEADX™	Up-flow	Planned
4	**Rain Water**	**Aged Material in Sand**	**Up-flow**	**Complete**
5	**Deionized Water**	**Sim. Aged Mat'l in Sand**	**Up-flow**	**Complete**
6	**Rain Water**	**+ Pb in Sand**	**Hold**	**In-Progress**
7	**Rain Water**	**+ Pb in Soil**	**Hold**	**In-progress**
8	Rain Water	Tracer Rounds in Sand	Up-flow	Planned
9	Rain Water	Bullets Fired into Soil	Up-flow	Planned

Tungsten
Significantly Less Toxic Alternative

Replacing Lead With Tungsten is Indicated By:

- **Dept. of Interior (Fish and Wildlife Service) 50 CFR Part 20 RIN 1018-AE66, "Migratory Bird Hunting; Temporary Approval of Tungsten Polymer Shot**
- **US EPA Has Not Identified Tungsten on Any Toxic or Hazardous Materials Listings Within Any Published Laws or Regulations.**
- **USACHPPM Report " Tungsten: A Review", W. McCain, DEC'98**
- **Oakridge National Laboratory Draft Report "Environmental Stability and Mobility of Tungsten as Part of Bullets Fabricated Using Non-Lead Materials", R. Lowden et al.**

Tungsten Metal is *Stable, Insoluble, Recyclable* and *Less Toxic* than the Alloys of Tungsten!!!

2000-2001
Ramp-Up to Full Scale Production

Despite the Success to Date, Problems Arise:

- **Accuracy Problems Encountered in Both Materials**

2. **Efforts to manufacture Core Samples Met w/ Mixed Results**
   Tungsten/Nylon: Corrective Actions Taken
   Tungsten/Tin: Degradation in Performance

- **Discrepancies Noted During Review of Tungsten/Tin Vendor Material Certifications**

Tungsten/Tin Test Matrix

		C60 Powder →						M70 Powder →					
	Lead	AOT 1	AOT 2	AOT 3	AOT 4	AOT 5	AOT 6	AOT 7	AOT 8	AOT 9	AOT 10	AOT 11	AOT 12
Horz Stand Dev	3.76	5.86	4.02	6.35	6.57	7.58	4.59	7.73	5.76	5.35	5.66	5.38	4.52
Vert Stand Dev	4.2	5.76	4.47	5.86	6.33	8.36	5.31	7.29	6.07	5.43	5.73	4.79	4.94
Core Length	0.4807	0.5069	0.5066	0.5055	0.5071	0.5036	0.5059	0.5063	0.5025	0.5047	0.5006	0.5026	0.4988
Core Weight	32.0	31.9	31.8	32.0	32.0	32.0	32.1	32.0	32.1	32.0	32.0	32.0	32.0
Bullet Length	0.907	0.919	0.917	0.918	0.916	0.915	0.917	0.918	0.917	0.918	0.914	0.916	0.917
Bullet Weight	62.3	62.5	62.5	62.3	62.3	62.3	62.3	62.4	62.6	62.6	62.4	62.4	62.5
Percent Stand Dev	NONE	4.7289	4.6114	8.3474	4.4594	5.8802	6.6563	4.8853	3.4063	1.2928	3.0723	9.4148	5.0171
Blend Size		L/15	LAB	LARGE	LARGE	LARGE	L/15	LAB	L/15	LARGE	LARGE	LARGE	L/15
TEMP		C	C	H	H	H	H	C	C	H	H	H	H
PRESS SET		O	O	O	1	2	0	0	0	0	1	2	0
%TIN		39.4	42.6	40.8	49.7	37.7	42.3	41.4	31.3	40.6	44.6	50.1	44.9
STD		4.7	4.6	8.3	4.5	5.8	6.7	4.9	3.4	1.3	3.1	9.4	5
Density (in) Ave		11.09	11.07	11.12	11.11	11.17	11.15	11.15	11.25	11.17	11.25	11.25	11.17
Density (in) STD		0.07	0.03	0.04	0.04	0.05	0.06	0.06	0.07	0.06	0.04	0.06	0.05

Lead	Control	AOT 7	Cold Lab Control
AOT 1	Cold 15 lbs (254)	AOT 8	Cold 15 lbs (Large Blend) Original
AOT 2	Cold 15 lbs Lab	AOT 9	Hot Large Original
AOT 3	Hot Large (254)	AOT 10	Hot Large Setting 1
AOT 4	Hot Large (254) Setting 1	AOT 11	Hot Large Setting 2
AOT 5	Hot Large (254) Setting 2	AOT 12	Hot 15 lbs (Large Blend) Setting 2
AOT 6	Hot Small Original		

2000-2001
Ramp-Up to Full Scale Production

Tungsten/Tin Findings

- C60 Tungsten Not Equivalent to M70 Due to Particle Size Distribution

- M70 Not as Process Dependent

- Additional Optimization Needed to Define Core Shape and Formability

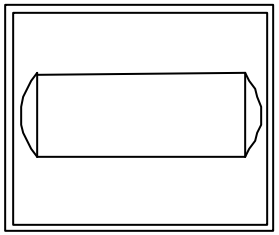
2000-2001
Ramp-Up to Full Scale Production

Optimization

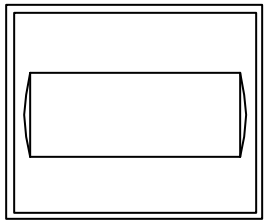
- **Tungsten/Nylon Optimization Study Performed First**
- **Parameters Investigate All Key to Lake City Production Processes**
- **Taguchi Type Experiment Analyzed the Following Parameters:**
  - **Diameter**
  - **Length (v)**
  - **End Configuration: Flat vs. Round vs. Profiled**
  - **Malleability of Material**
- **Tungsten/Tin Effort to Include Lessons Learned From Nylon Study**

2000-2001

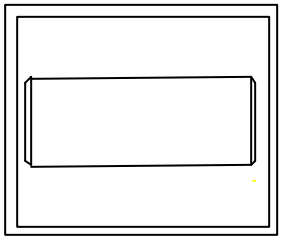
Ramp-Up to Full Scale Production



Lead Shape



Rounded



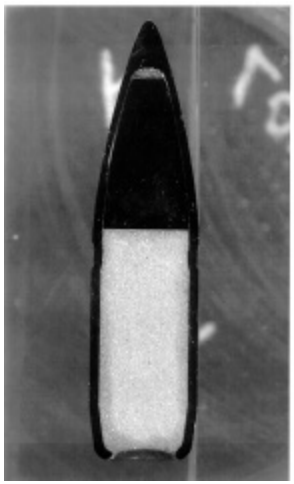
Flat End

Densities: 10.8 - 11.0 g/cc

Weight: 31.7 – 32.0 grains

Blends: **Original** vs. More Malleable

Tungsten – Nylon 12

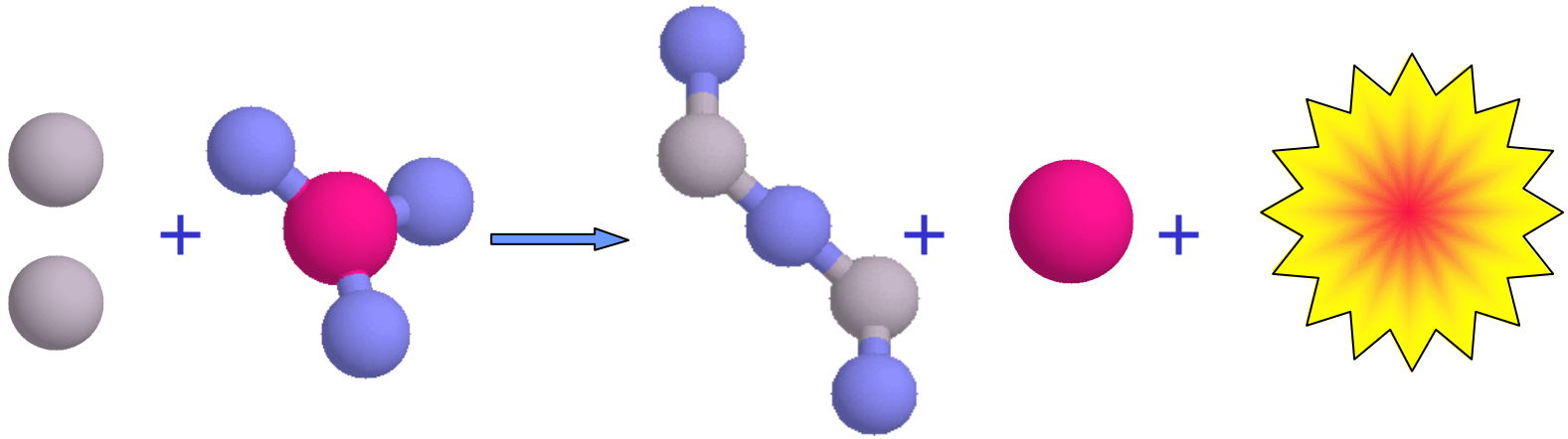


Primer Replacement Effort

METASTABLE INTERMOLECULAR COMPOSITES

- New Family of Highly Energetic Materials
- Tailored from Joint DoD\DoE Development Program
- Function Not Effected by Temperature
- Resistant to Water Degradation

Chemical Reaction of MIC



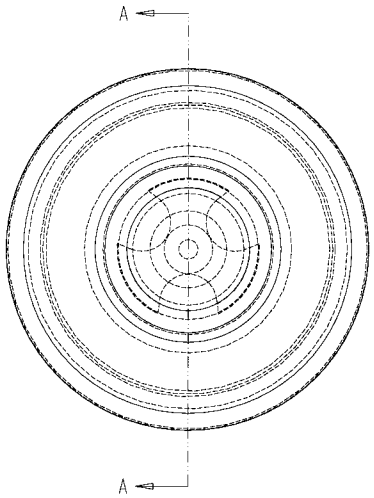
2Al + MoO_3 → Al_2O_3 + Mo + Heat

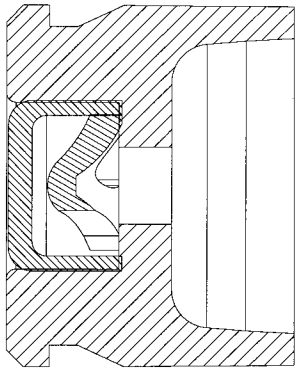
crystal lattice segment

Small Caliber Ammunition
Primer Configuration

5.56 mm primer cup and anvil

MIC-loaded 5.56 mm primer



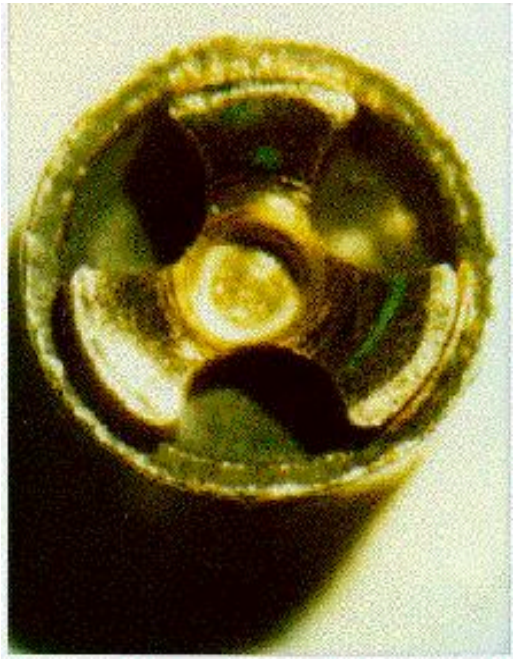


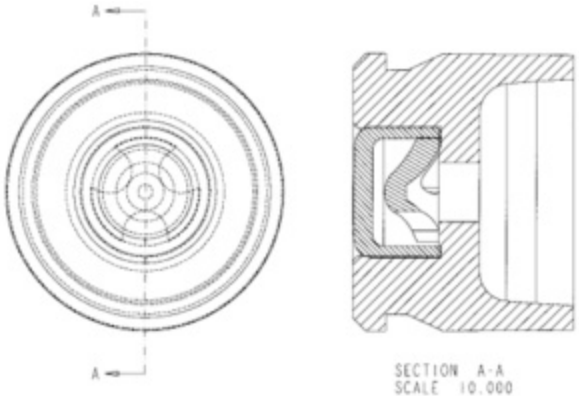
SECTION A-A
SCALE 10.000

PRIMER NO. 41
10534279
REF. 1 B

Performance Testing

- **Initial Experiments Analyzed the Following Parameters:**
  - **> Flash Hole Size**
  - **> Temperature Effects**
  - **> Standard MIC (760 m/s) vs. “Slow” MIC (560 m/s)**
  - **> LCAAP Anvil vs. PVU Anvil**
- **Taguchi Experiment Analyzed the Following Parameters:**
  - **> Pellet Weight**
  - **> Anvil Shape & Height**
  - **> Primer Cup Base Thickness**
  - **> Seating Depth**
  - **> Flash Hole Size**
  - **> Paper/No Paper**





Performance Test Results

Test Results:

- Temperature Insensitivity
- Flash Hole Effects Action Time
- PVU Anvil Minimal Effect
- MIC Burn Rate Effects Action Time

Taguchi Results:

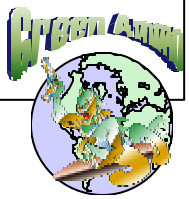
Key Critical Parameters for Action Time:

1) Pellet Weight (Heavier)
2) Seating Depth (Deeper)
3) Cup Thickness (Thinner)

Key Critical Parameters for Sensitivity:

1) Anvil Shape (Pointier)
2) Cup Thickness (Thinner)
3) Anvil Height (Taller)

Listed in Rank Order



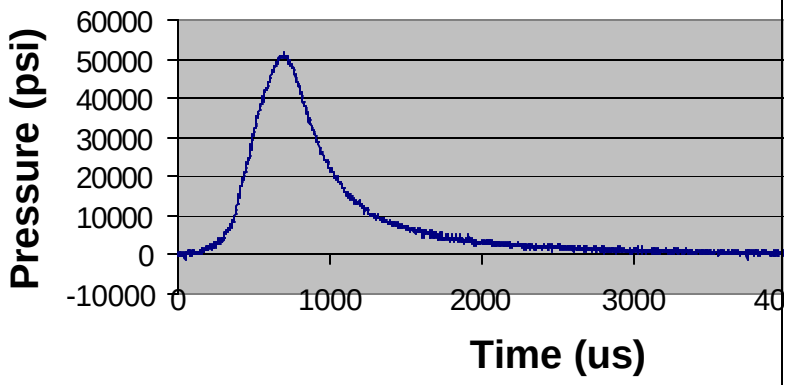
Phase II Testing

- Best Configurations from Taguchi Experiment Tested in Full-Up Cartridges
- Additional Primers Manufactured at LANL
  - >A) Anvil (Pointed/Tall), No Paper, Thin Base Cup
  - >B) Anvil (Pointed/Tall), No Paper, Standard Thickness Cup
- CAD - Hot (+155^{O}F), Cold (-65^{O}F), Ambient Testing
- Full-Up Cartridge Testing (Ambient, Hot, Cold)
  - >Electronic Pressure, Velocity & Action Time Barrel
  - >M16 Weapon
- 5.56mm Primers with 7.62mm Cases
- Long Term Storage Test on Best Configuration to Begin Shortly
- Pellet Integrity Testing to Begin Shortly

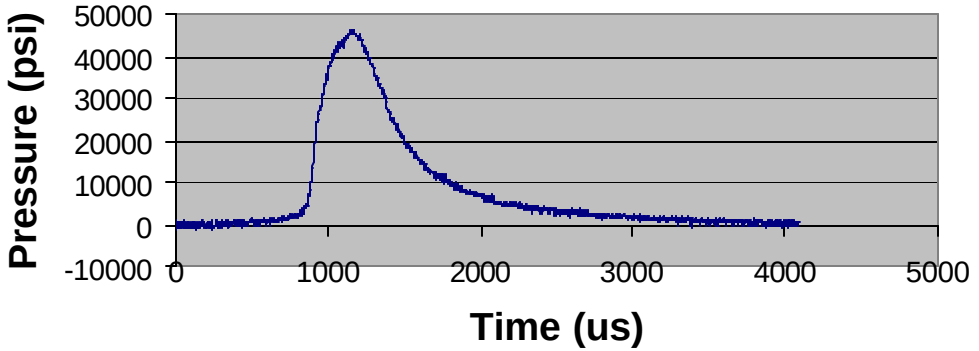
MIC Test

Ambient Temperature

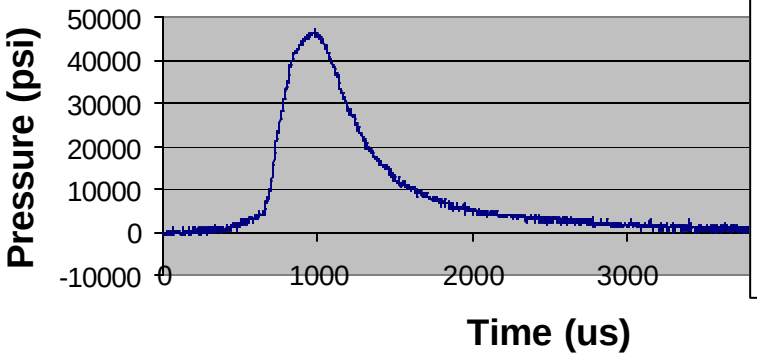
Reference Lot



Config B



Config A



Avg's	Mid Case (psi)	**Act Time (us)**	Velocity (f/s)
Lot_28	47,801	**1,910**	2,932
Lot_26	44,923	**1,721**	2,888
Ref Avg	50,750	**1,197**	2,979

Future Testing

- Analyze Affect of Al/MoO_3 Ratio (S)
- Analyze Affect of Particle Size & Shape (S)
- Long Term Storage Test on Best Config to Begin Shortly (S)
- Affect of Thickness of Passivation Layer on Long Term Storage/Performance
- Determination of weapon fouling as a function of oxide layer on MIC particle.
- Determination of pellet integrity boundaries.
- The affect on performance as a result of three different Al manufacturers (LANL, ARDEC, IH)
- The affect on performance as a result of different MoO_3 manufacturers (Government, Industry)

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